Estimating the Length of Oiled Marsh Shoreline in Louisiana from the *Deepwater Horizon* Spill

Technical Report

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Abstract

The length of oiled Louisiana shoreline that resulted from the *Deepwater Horizon* spill is one of the key metrics used to support the injury quantification for the associated natural resource damage assessment (NRDA). Initial synthesis of oiling observations from the response and the NRDA activities used a 2008 shoreline as a spatial reference. Use of the 2008 shoreline consistently underestimated shoreline length compared to the complex shoreline that was actually oiled in 2010. We used spatial analysis tools available in ArcGIS to restore the field-collected data to the 2010 shoreline and to recalculate the total length of oiled marsh in Louisiana. Based on this study, the length of oiled shoreline in Louisiana was ~ 10–40% longer than estimated from previous studies in which the 2008 shoreline was used. This report documents the methods, results, and uncertainties associated with our study.

1. Introduction

During the course of the *Deepwater Horizon* oil spill, Shoreline Cleanup and Assessment Technique (SCAT) teams working on response activities compiled a substantial body of observational data describing the nature and extent of marsh shoreline oiling. These field teams recorded oiling observations on paper maps and marked their positions with hand-held global positioning system (GPS) units in track mode. These raw field observations were then compiled as geographic information system (GIS) layers using a digital shoreline feature from 2008 as a spatial reference (e.g., Nixon et al., 2015). The SCAT dataset was later combined with other observational datasets, most notably the Rapid Assessment dataset, to generate a more comprehensive shoreline exposure database for the natural resource damage assessment (NRDA; e.g., Nixon et al., 2015). This Gulf-wide shoreline exposure database also used the 2008 shoreline as a spatial reference, with some modifications.

Although the 2008 shoreline was a readily available spatial reference for compiling Gulf-wide observational data during the response efforts, this feature represented the land-water interface at a relatively low tide, two years before the spill. As a result, the vegetated marsh edge where SCAT teams made their observations in 2010 is typically landward of this line (e.g., Nixon et al., 2015; Figure 1), and is more detailed than the representation of the shoreline from 2008. In addition, because of the way the response information was initially compiled, some of the field data collected by SCAT teams may not have been fully used in assigning this information onto the 2008 shoreline. For all of these reasons, shoreline lengths based on the 2008 data layer underestimated the true length of the vegetated marsh shoreline, particularly in the complex marsh habitats of Louisiana.

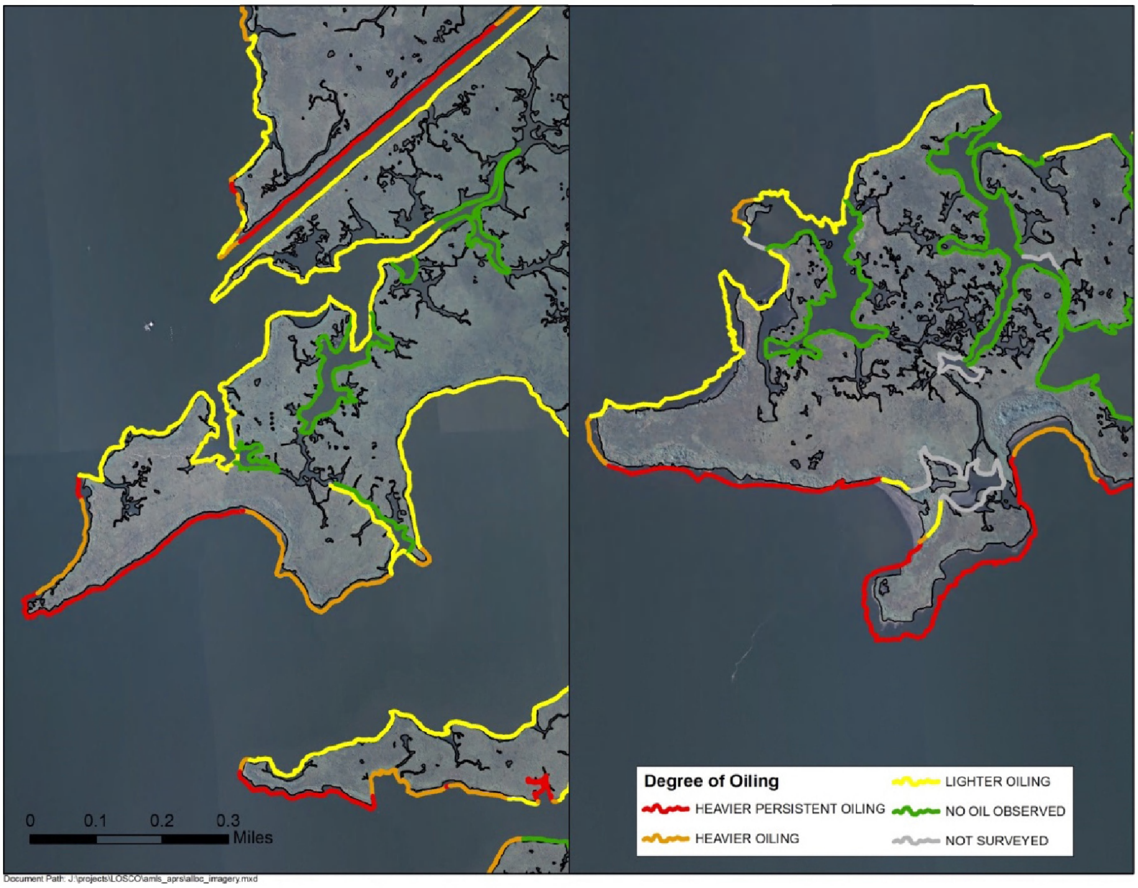

Figure 1. Oiling data as represented by the shoreline exposure product (thick, colored outlines) compared to the actual shoreline from 2010 imagery (thin black lines along light grey land edges). Note that the actual shoreline is typically landward of, and more complex than, the lines generated from 2008 imagery.

In an effort to improve the representation of oiling along the Louisiana marsh edge, we transferred the oiling data from both the shoreline exposure database and the cumulative SCAT database onto a digital representation of the shoreline generated from 2010 high-resolution aerial imagery. The goals of this study were to depict field observations of oiling using the best available digital representation of the shoreline, and to refine the estimates of oiled length for Louisiana marsh habitats. This technical report summarizes the steps we took to complete this analysis and the resulting changes in oiled shoreline length.

2. Input Data and Methods

2.1 Shoreline Oiling Data

The two primary data sources that summarize shoreline oiling from the *Deepwater Horizon* spill are the SCAT database and the shoreline exposure database. In both cases, the data represent oiling characteristics from 2010 surveys attributed to the 2008 shoreline. We transferred (i.e., "allocated") information from both of these datasets onto the 2010 shoreline, and generated updated versions of both SCAT and shoreline exposure products. For this report, we focus on results from the shoreline exposure database because this is the product most commonly referenced in the Programmatic Damage Assessment and Restoration Plan (PDARP) injury volume.

We completed the majority of our work in the spring and early summer of 2015, using shoreline oiling datasets current as of the fall of 2014. However, we note that the shoreline exposure dataset has undergone multiple rounds of updates, so there may have been minor discrepancies in the raw, "unallocated" shoreline oiling lengths we used, and those reported in other parts of the PDARP. We downloaded the shoreline exposure database for our analysis in September 2014.

2.2 Land/Water Data

For the 2010 shoreline, we used a shoreline generated by the United States Geological Survey (USGS, 2013), which we downloaded from ERMA (2015) in April 2014. The 2010 USGS data contained a land/water attribute, where "land" represented all non-submerged vegetation types and "water" represented all submerged types of wetlands, as well as tidal flats, beaches, and water classes. This high-resolution shoreline product was available for 48 7.5-minute quadrangles across the central Louisiana coast, all of which the Trustees identified as priority areas for the NRDA (Figure 2).

As illustrated in Figure 2, these 48 priority quadrangles did not encompass all of the Louisiana shoreline where oiling was observed by response and NRDA teams. For parts of Louisiana where the shoreline exposure product indicated oiling but high-resolution shoreline data were unavailable, we generated a shoreline from 2010 aerial imagery using standard image classification techniques to assign each pixel in the raw image to either a land or water class. To do this, we used a clustering analysis function (i.e., "isocluster"), available in the spatial analyst module of ArcGIS (v. 10.2), which places pixels with similar spectral characteristics into unique groups. Each output group was then visually compared to the raw imagery and manually reclassified into land; water; or indeterminate, meaning pixel classes that spanned both land and

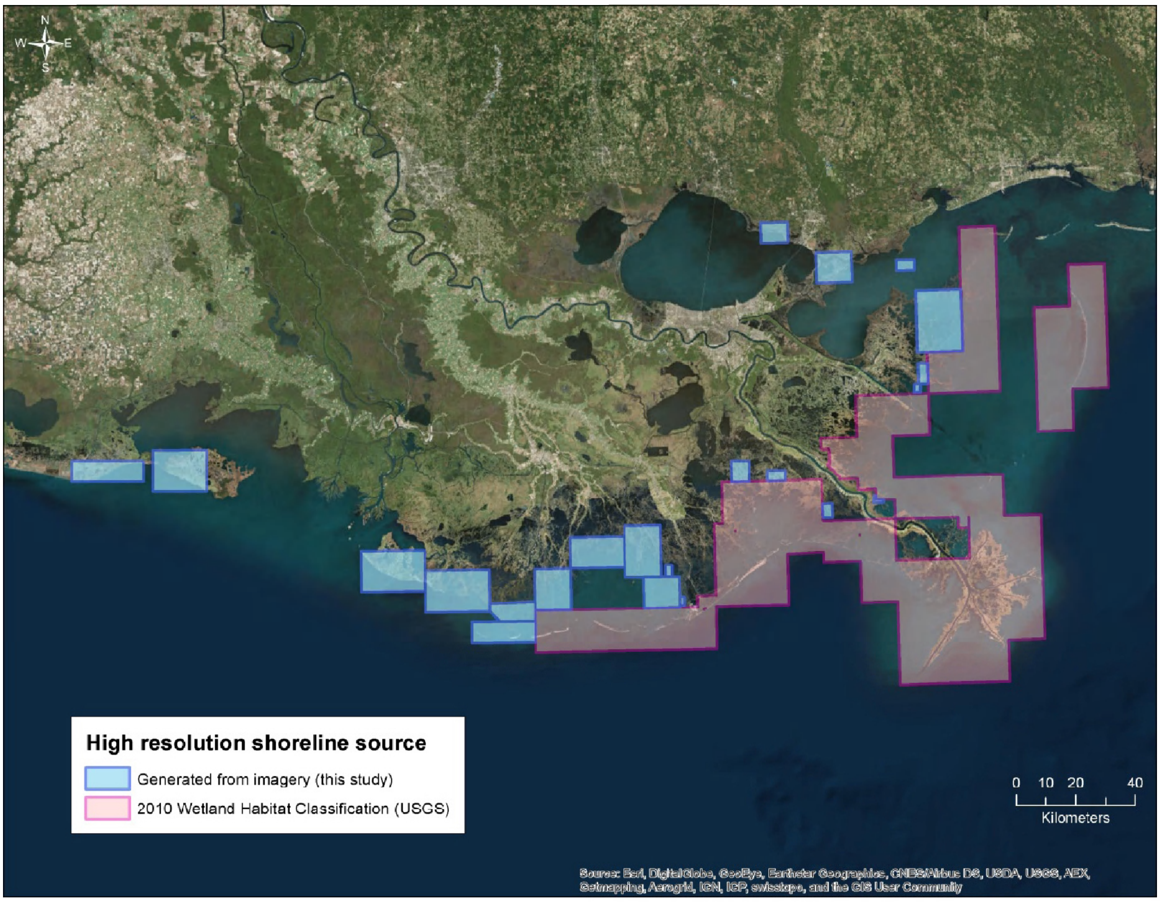

Figure 2. Quadrangles with high-resolution shorelines from 2010 aerial imagery. The USGS processed the high-resolution shoreline in the pink “priority” quadrangles, and we generated the high-resolution shoreline in the blue areas. The combined high-resolution shoreline product encompassed all Louisiana shorelines where oiling was observed.

water. We then extracted the groups with indeterminate classes and repeated the process on this subset of pixels until all areas within the scene were classified as either land or water. We then converted the classified image from raster to vector format, and smoothed the edges to create a final shoreline product. As in the 2010 USGS product, our product classified all pixels into one of two categories – land or water – and tidal flats were typically classified as water (Figure 3).

The aerial imagery we used to generate this shoreline came from the same set of imagery that USGS used to generate the 2010 USGS product, so that the entire high-resolution shoreline in Louisiana came from a single primary data source.

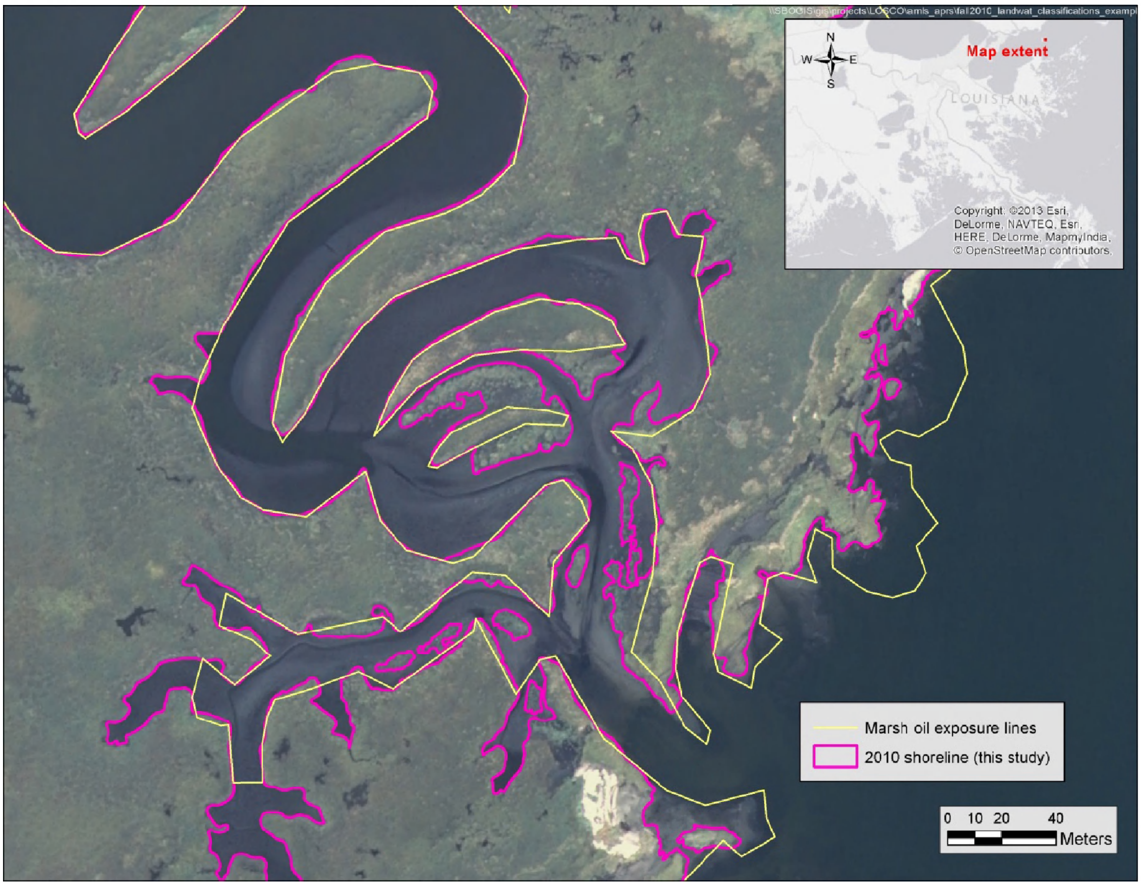

Figure 3. Example of shoreline generated from 2010 aerial imagery (pink) compared to original 2008 shoreline used for SCAT and shoreline exposure databases (yellow).

3. Allocation Process

Once the high-resolution shoreline was generated for all portions of the shoreline where oiling was observed, the next step was to translate the oiling data as depicted on the 2008 shoreline back onto the 2010 shoreline, where the field observations were originally made. To do this, we used a "cost-allocation" process in ArcGIS, which assigned an oiling value to each segment of the 2010 shoreline based on the nearest oiling value from the 2008 shoreline within a specified distance. In the cost-allocation process, the distance between points was also weighted by the relative "cost" of traversing pixels with different classifications. For our purposes, this cost classification was used to ensure that oiling attributes were allocated across water, but not across land. This reduced the likelihood that oiling attributes would be misallocated (e.g., to a shoreline on the opposite side of an island from the location of the initial oiling observations). We assigned a cost value of 1 for water pixels, and a cost value of 10 for land pixels. We saved these land/water cost values as a "cost surface" representing the domain of the entire Louisiana coastline where oiling occurred.

The cost allocation function required a limit on the maximum distance that oiling values could be allocated. This value was expressed in terms of a "cost distance," so that in our case a distance of 10 meters across water was equivalent to a distance of 1 meter across land. It is important to note that the cost-allocation algorithm would not assign any oiling value to the 2010 shoreline if the allocation distance was too short. For example, if the maximum allocation distance was 50 meters, the 2010 shoreline would not be assigned any oiling value in places where the 2008 and 2010 shorelines were more than 50 meters apart. We selected our allocation distance and cost surface to ensure that (1) oiling information was not lost in the process, and (2) we did not inadvertently allocate an oiling value to locations beyond where field observations were made.

To choose an appropriate allocation distance, we selected data from three USGS quadrangles. These quadrangles represented a range of marsh habitats in Louisiana: South Pass on the Mississippi Delta, Bay Batiste in Barataria Bay, and Bay Tambour between Barataria and the Delta. For each quadrangle, we extracted all of the vertices from the 2008 SCAT shoreline and calculated the distance from each vertex to the nearest point on the 2010 shoreline. This yielded approximately 22,000 to 35,000 distance values for each quad, which we combined to create a sample of how far apart the two shoreline features were (Figure 4). We then calculated the 90th, 95th, and 99th percentiles from this combined dataset. Based on this analysis, we chose a cost allocation distance of 50 meters. This was approximately the 99th percentile of all measured distances between the 2008 and 2010 shorelines. On average, we therefore could expect that more than 99% of the shoreline oiling data were successfully allocated to the true shoreline.

To run the allocation process, we first converted the shoreline exposure vectors to a grid format at a 1-meter cell resolution. We attributed each cell value in these grids with numeric values representing the shoreline exposure category for that shoreline segment. We then ran the cost allocation function within the spatial analyst module in ArcGIS to allocate the oil attributes from the shoreline exposure grid to a cost-allocation surface. The value of each cell in the output surface was assigned to the closest source cell, based on the lowest cumulative cost over the cost surface. Based on our analysis of separation distance between the 2008 and 2010 shoreline features (Figure 4), we then selected only those cells in the allocated surface that were less than 50 cost-cells away. Thus, the nearest 50 water cells to the source cell were included in the allocation, but only the nearest 5 land cells were included (Figure 5). We then selected only the land cells from the allocated surface, and converted these cells to a polygon feature that retained the oil category. Finally, we buffered the polygon by an additional meter to ensure that the original shoreline was enclosed, and ran an intersection analysis to transfer the oil category attribute to the 2010 shoreline. Figure 6 shows an example of the final allocated shoreline.

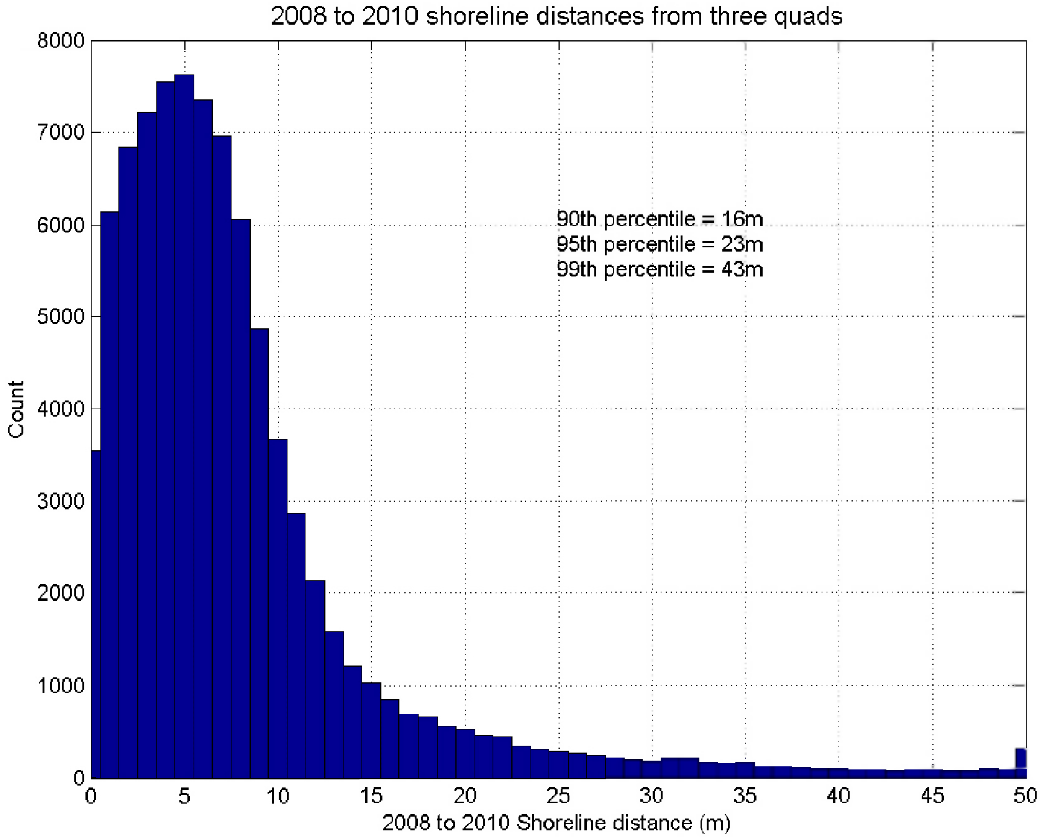

Figure 4. Histogram of measured distances between 2008 and 2010 shorelines. Based on this analysis, we chose an allocation distance of 50 meters. This choice ensured that less than 1% of the oiling information from the 2008 shoreline was lost in the allocation process.

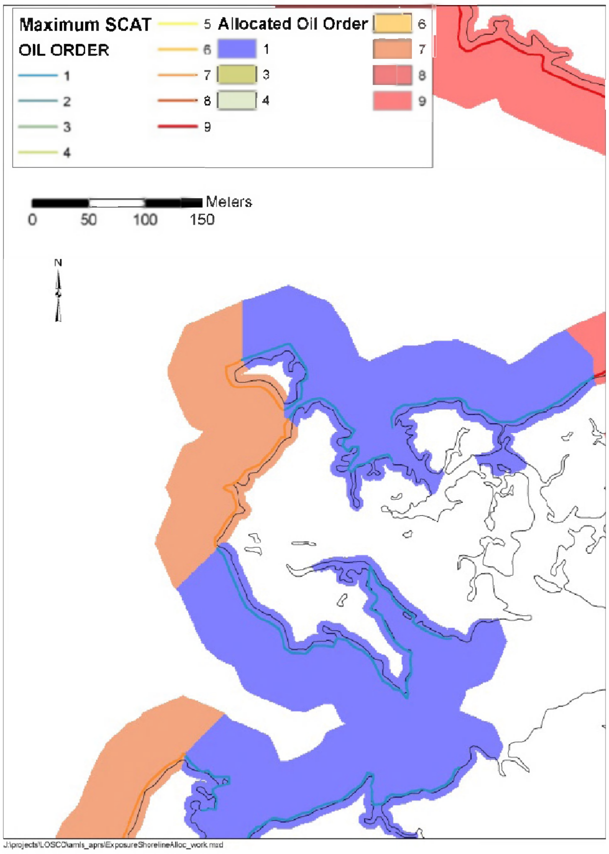

Figure 5. Cost-allocation mask showing allocated oil categories within 50 cost cells from SCAT.

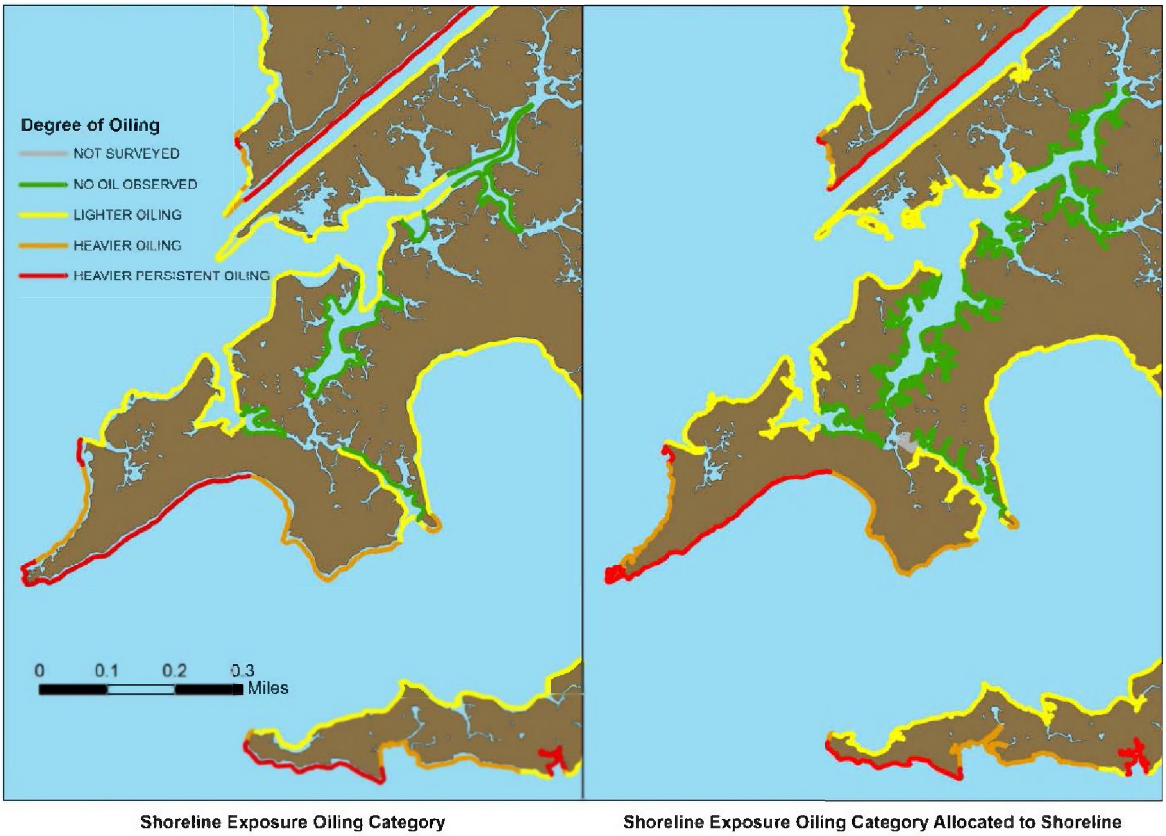

Figure 6. Example of oiling attributes from the 2008 shoreline (left side) translated onto the 2010 shoreline (right side).

4. Results

The allocation of shoreline exposure data onto the 2010 shoreline increased the measured length of oiling for nearly all segments of the Louisiana coastline. The relative change between the shorelines varied among oiling categories and marsh types, but the 2010 marsh shoreline oiled was approximately 40% longer than documented in the shoreline exposure database. The cost-allocation process allocated oiling information not only onto the relatively straight shorelines immediately adjacent to the 2008 shoreline feature, but also up to 50 meters into the channels and inlets that were resolved by the more detailed 2010 coastline. As a result, the increased oiled length resulted from a combination of increased complexity of the marsh edge itself, and the additional shoreline length associated with allocating oiling data into channels and inlets. To evaluate the relative contributions of different sources of added length, we undertook a series of additional quantitative and qualitative analyses. First, we analyzed a series of shoreline segments without significant channelization to isolate the added length coming purely from increased shoreline complexity. Second, we compared SCAT lines to raw GPS track logs to evaluate whether field observations from channels and inlets might have been lost when these data were transferred onto the 2008 shoreline.

4.1 Isolating Channels and Inlets

To remove the influence of channels and inlets on the added shoreline length, we selected 50 shoreline segments in coastal Louisiana that did not include any significant channelization or fragmentation. For each of these shoreline segments, we manually traced an approximately 1-kilometer long segment of the shoreline, and buffered this line to select both the 2008 and 2010 shorelines. We then tabulated the lengths of these individual segments and the fractional change in length between the two shorelines.

Figure 7 shows the results of this analysis. There was substantial spread in the data, with some segment lengths changing by less than 5% and others increasing by up to 55%. However, our analysis indicated that on average, 12% of the increased oiling length from the allocation process came simply from increased shoreline complexity, rather than from allocating oiling data into channels and inlets. Figures 8–10 show three examples of the 50 shoreline segments underlying this analysis.

4.2 Comparisons to Raw Field Data

Based on the comparisons described above, approximately one-third of the increase in oiled length between the 2008 and 2010 shorelines (i.e., 12% of the ~ 40% total increase) resulted simply from the complexity of the vegetated marsh edge in 2010, compared to the original representation of the land-water interface at a much lower tide in 2008. In these cases, it was appropriate to use the digital representation of the shoreline that most closely represented the vegetated marsh edge where field observations were originally collected.

The remainder of the increase in oiled length resulted from allocation of oiling information into channels and inlets along the Louisiana coastline. Although there may have been cases where our choice of a 50-meter allocation distance "over-allocated" oiling into these channels, multiple lines of evidence demonstrated that the original transfer of raw field data to the 2008 shoreline commonly "under-allocated" these observational data. To qualitatively investigate whether over-allocation or under-allocation was more common, we sought to compare the raw field data to the different representations of the shoreline in areas with significant channels and inlets.

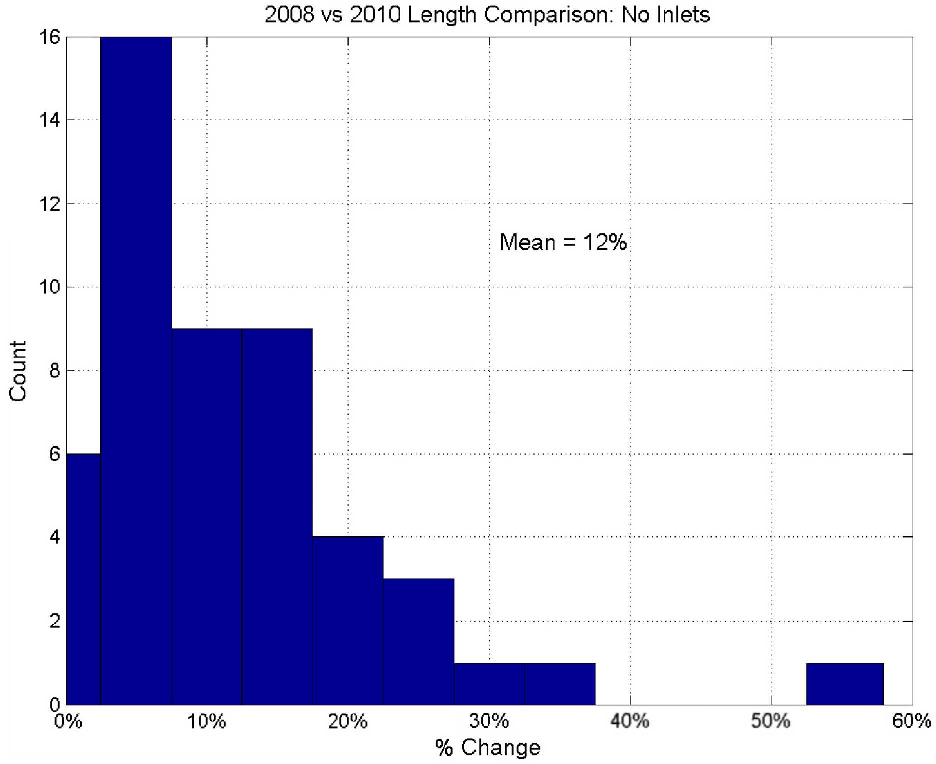

Figure 7. Histogram of changes in length along shoreline segments without significant channelization.

Figure 8. Example of shoreline segments from Louisiana marshes with a difference in length of 5% between the 2008 and 2010 shoreline products.

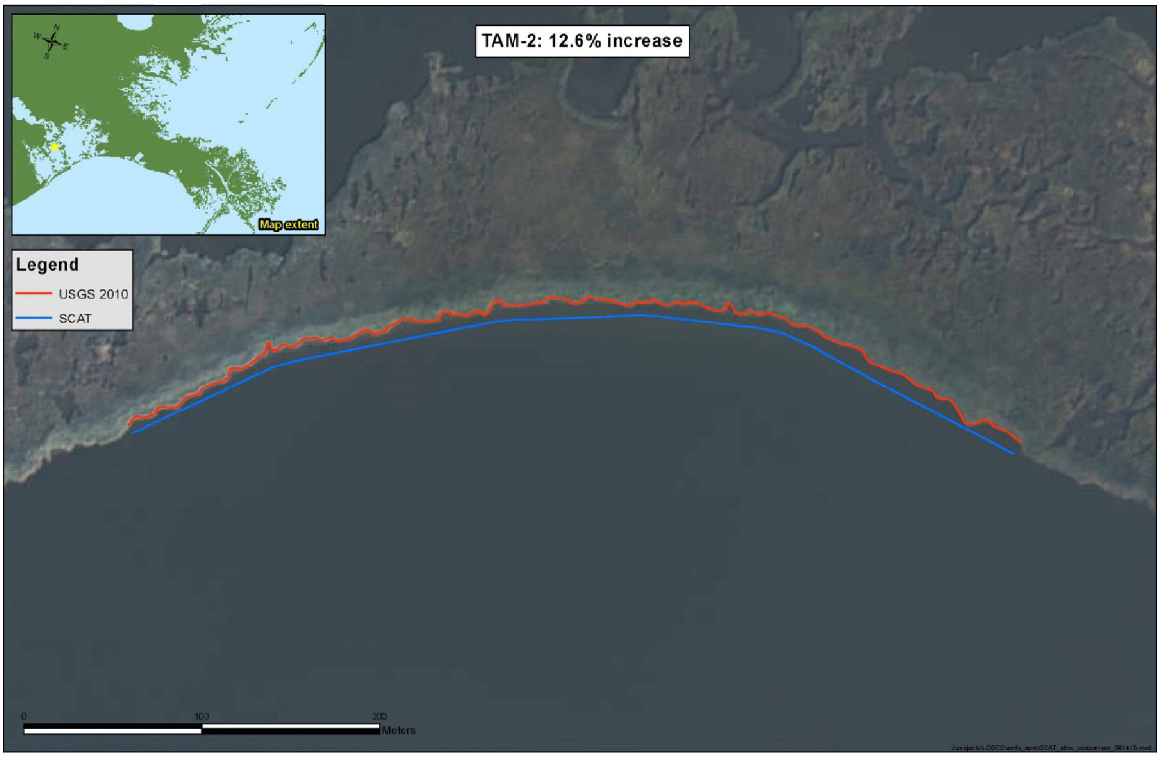

Figure 9. Example of shoreline segments from Louisiana marshes with a difference in length of 13% between the 2008 and 2010 shoreline products.

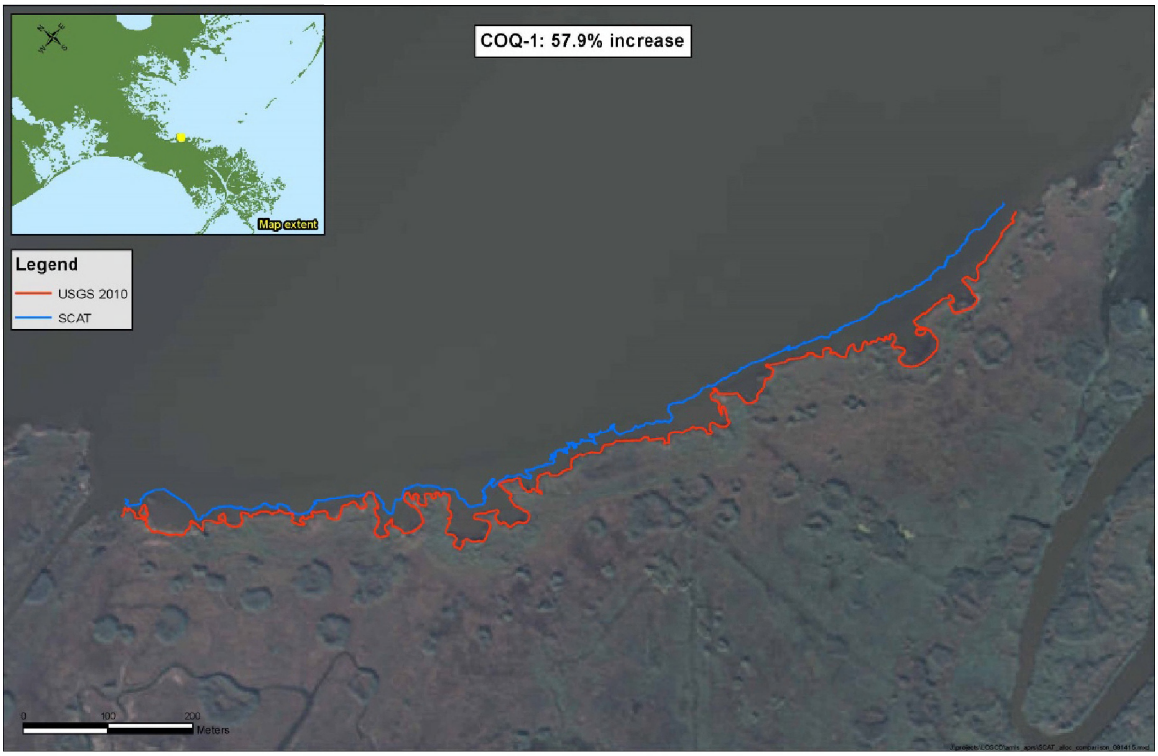

Figure 10. Example of shoreline segments from Louisiana marshes with a difference in length of 58% between the 2008 and 2010 shoreline products.

In general, the raw, hand-drawn maps that SCAT teams brought back from the field each day were not readily available to evaluate whether over-allocation or under-allocation was more common. However, from the GPS track logs that we were able to obtain, there were many examples where a comparison of the SCAT product to these track logs suggested that under-allocation was common. This implied that in many of these channels and inlets, our allocation process may have simply restored field observations closer to the shorelines where they were originally collected.

Figures 11 and 12 show two examples of waypoints and track logs collected in the field, along with the corresponding digital representation of these data onto the 2008 shoreline. Figure 11 indicates that this SCAT team went approximately 100 meters into the large north-south channel in the center of the image on May 30, 2012. Because light oiling was observed outside of this inlet, and because there were no breaks in SCAT category at the channel mouth, we assume that this team observed light oiling along both inner banks of this channel on this date. The SCAT line, however, crosses over the mouth of the channel, suggesting that the length of lightly oiled shoreline in this scene was underestimated (Figure 11).

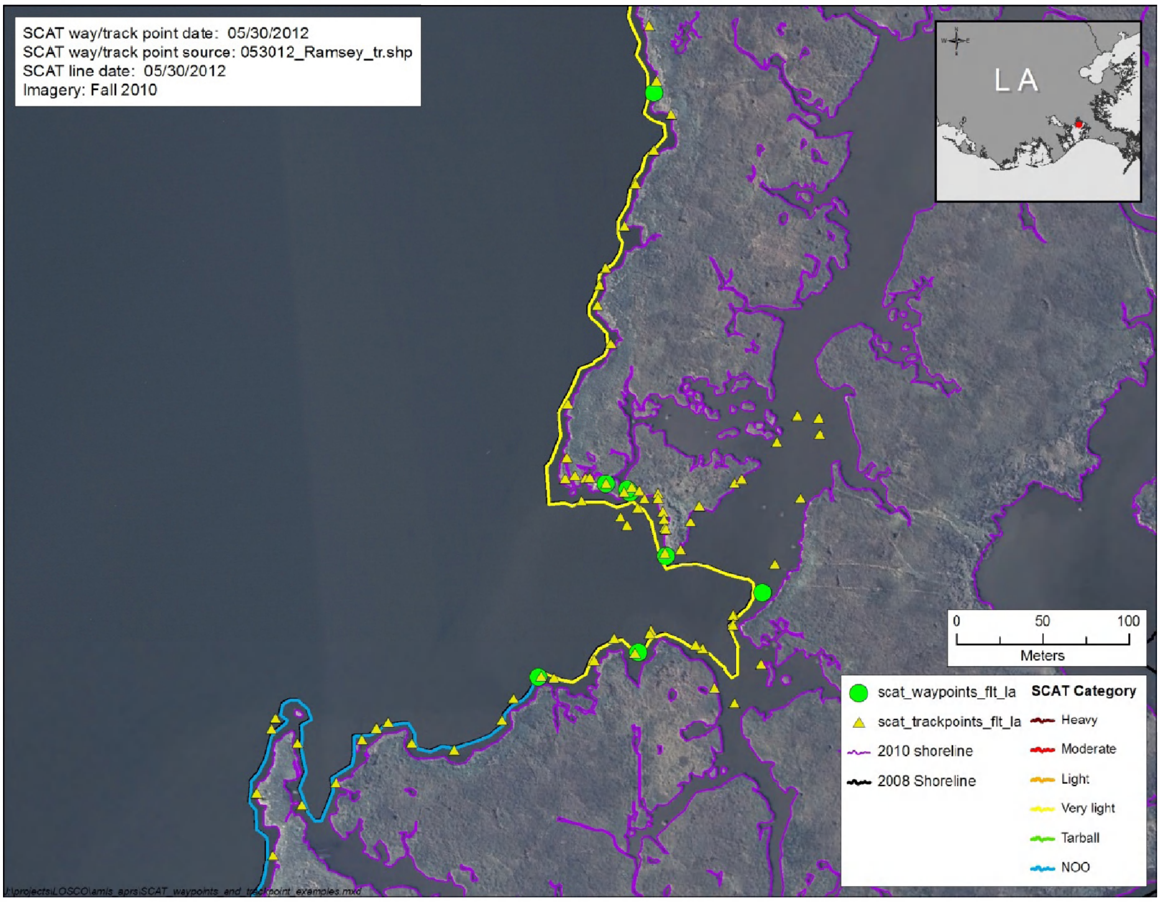

Figure 11. Comparison of SCAT shoreline and field team track log (yellow triangles) from May 30, 2012, demonstrating that SCAT teams made observations > 100 meters deeper into the marsh than represented by the SCAT product from that date.

Figure 12. Comparison of SCAT shoreline and field team track log from July 9, 2010, demonstrating that SCAT teams made observations > 25 meters deeper into the marsh than represented by the SCAT product from that date.

Figure 12 shows a track log that closely followed the 2010 shoreline, and indicates that this field team also made observations along the banks of two small inlets that were 25 to 50 meters deep. Based on the color of the SCAT line along the 2008 shoreline, the SCAT team observed moderate oiling inside the smaller of these two inlets (oriented roughly north-south, in the center of the scene). The length of this moderately oiled segment, however, was underestimated by the 2008 shoreline onto which these observations were projected (Figure 12).

Figure 12 also suggests that the way oil was transported during the *Deepwater Horizon* spill may have actually favored the fouling of channels and inlets along Louisiana's complex coastline. With the exception of four short segments of moderate oiling, the entire shoreline shown in Figure 12 was labeled as "no observed oil" (NOO). The four "moderate" oiling segments were all associated with various degrees of concavity along the shoreline, suggesting that oil became concentrated in sheltered inlets along the marsh edge.

High-resolution multispectral imagery collected during the spill supports this idea. Figures 13 and 14 show two examples of images collected by Ocean Imaging, Inc., to help support response actions during the spill. In both of these examples, oiling on water and vegetation were concentrated deep inside channels, well beyond where SCAT teams were able to go. These images suggest that even our allocation distance of 50 meters might not have fully captured the degree of oiling in the channels and inlets of Louisiana's marshes.

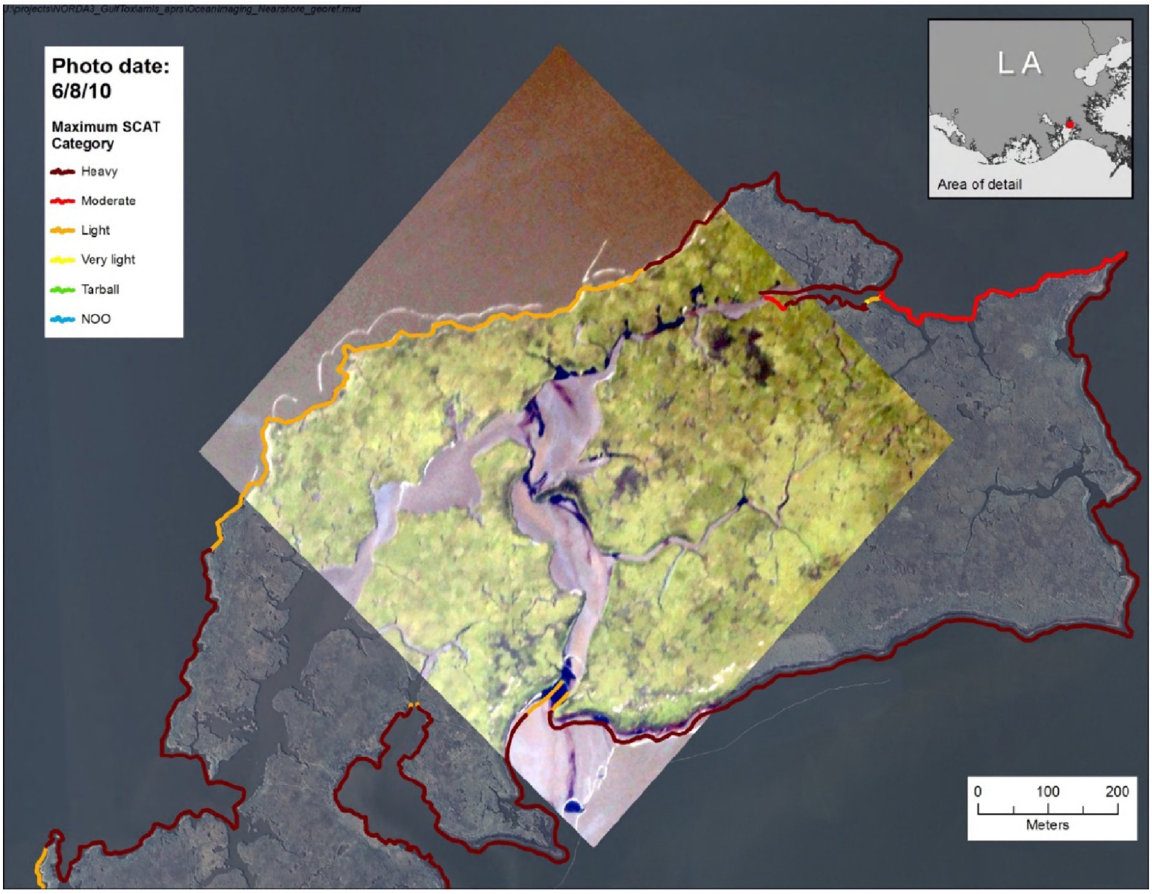

Figure 13. High-resolution imagery from June 8, 2010, compared to maximum SCAT category from northern Barataria Bay. Black patches in the center of the image represent oiling of water and vegetation deep within the marsh interior, hundreds of meters beyond where SCAT teams were able to go.

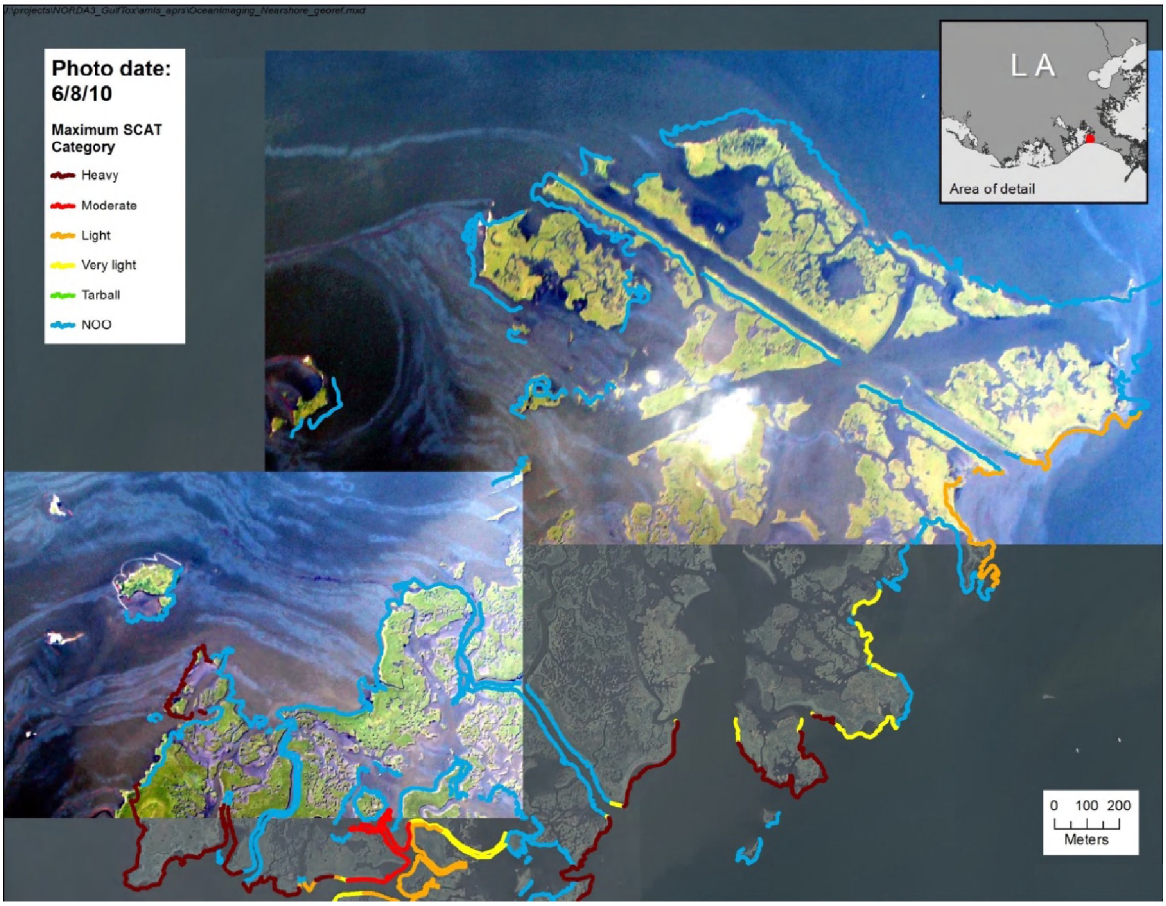

Figure 14. High-resolution imagery from June 8, 2010, compared to maximum SCAT category from eastern Barataria Bay. Dark blue/black patches at the top of the image and sheen on the water indicate oiling in many marsh areas that were never surveyed, or that had a maximum SCAT category of NOO. Note that these were oblique aerial photographs; the disconnect between SCAT lines and shoreline stems from image registration issues.

Although many of these observations were qualitative, the information we collected suggested that our cost allocation with a 50-meter allocation distance may still have underestimated the degree of oiling in the channels and inlets along the Louisiana marsh edge. Specifically:

- GPS waypoints and track logs indicated that some of the original field observations collected by SCAT and Rapid Assessment teams may have been lost when this information was transferred to the 2008 shoreline feature

- SCAT data from some locations indicated that oiling may actually have concentrated in concavities along the marsh edge, suggesting that allocation of data back into these inlets may have been appropriate
- High-resolution imagery collected during the response demonstrated that oil became concentrated deep within channels and inlets in many locations where SCAT teams did not collect field data.

5. Summary

During the *Deepwater Horizon* spill, there was a need to efficiently synthesize field information and reference this information to a common shoreline feature. At the time, the best available representation of the shoreline was a digital product from 2008, which was based on imagery collected at a relatively low tide two years before the spill. In the years after the spill, however, a higher-resolution shoreline product based on 2010 imagery became available. This imagery more accurately reflects the shoreline where oiling actually occurred in 2010. When we transferred oiling data from the 2008 shoreline onto the 2010 shoreline using a cost-allocation process, the oiled length in Louisiana marshes increased by approximately 40%.

Sensitivity analyses demonstrated that approximately 12% of the increased length results simply from the added complexity of the 2010 vegetated marsh edge relative to the lower-tide line from 2008. The remaining increase results from allocating oiling information up to 50 meters into channels and inlets, many of which were not accurately represented by the 2008 shoreline. Data collected as part of response efforts, including GPS track logs, observations of oil concentrating within concave segments of the marsh edge, and aerial imagery all suggest that our revised estimate of shoreline oiling length may still have underestimated the true scale of oiling along Louisiana's complex marsh edge. However, lacking quantitative estimates on how much oiling occurred in channels and inlets, our best quantification of the actual length of oiled marsh in Louisiana is 12% to 40% higher than the values reported in the shoreline exposure database.

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